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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MSC INTERNAL NOTE NO 67-FM-74

June 2, 1967

VELOCITY REQUIREMENTS FOR VENUS
ORBITAL MISSIONS DURING 1970 TO
1975 USING FREE-RETURN OUTBOUND
TRAJECTORIES

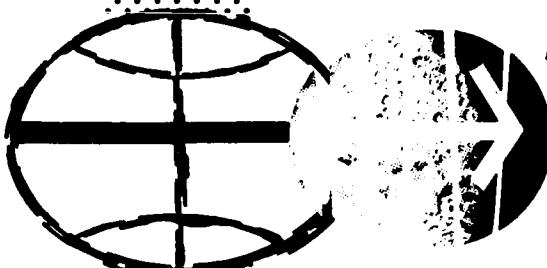
By John T. McNeely

Advanced Mission Design Branch



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MISSION PLANNING AND ANALYSIS DIVISION

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(NASA-TM-X-69439) VELOCITY REQUIREMENTS
FOR VENUS ORBITAL MISSIONS DURING 1970
TO 1975 USING FREE-RETURN OUTBOUND
TRAJECTORIES (NASA) 24 p

N74-70667

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Unclassified
16281

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VELOCITY REQUIREMENTS FOR VENUS ORBITAL MISSIONS DURING 1970 TO 1975
USING FREE-RETURN OUTBOUND TRAJECTORIES

By John T. McNeely

SUMMARY

A study has been made of the velocity requirements for Venus orbital missions between 1970 and 1975 using outbound heliocentric trajectories which are free-return to Earth. The outbound trip times vary between 76 and 146 days. Stay times between 0 and 30 days are considered, and the resulting total trip times are between 350 and 475 days. Two orbits around Venus are considered: a 100- by 80 000-n. mi. orbit and a 1000- by 80 000-n. mi. orbit. In all cases, the 100- by 80 000-n. mi. orbit requires the least velocity change. Of the four launch periods considered between 1970 and 1975, the minimum velocity missions occur during 1975.

INTRODUCTION

One of the goals of manned exploration of space may be the exploration of the planet Venus. Much more information can be obtained from orbital missions than from flyby missions. In studies of flyby missions, both free return and powered-turn (ref. 1, 2, and 3), it is shown that Venus orbital missions will require less velocity than similar missions to Mars. Venus missions also have much shorter total trip times.

The free return trajectories to Venus analyzed in reference 3 have outbound trip times between 76 and 146 days. Because of unforeseeable operational problems, it might be desirable to use a free-return trajectory when a planetary orbital mission is attempted. For that reason, in this study the outbound portion of an orbital mission is a free-return trajectory. Stay times between 0 and 30 days are considered, and the resulting total trip times are between 350 and 475 days. The transearth injection velocity is minimized.

Since free-return trajectories are not necessarily minimum injection velocity missions, any flight using the outbound segment of a free-return trajectory will not necessarily be a minimum velocity mission.

The author wishes to express his appreciation to Mr. Benjamine J. Garland for the use of his Conic Interplanetary Computer Program (ref. 1 and 2), which was used to generate the data for this report.

ANALYSIS

This study was made to determine velocity requirements for Venus orbital missions. The velocity required for deboosting into orbit around Venus is simply the difference between the periapsis velocity of the incoming hyperbola and the periapsis velocity of the orbit around Venus. Likewise, the transearth injection velocity is the difference between the periapsis velocity of the escape hyperbola and the periapsis velocity of the orbit around Venus. No provisions were made for orbital perturbations. Figure 1 shows the motion of the spacecraft within the sphere of influence of Venus. The inbound trip time was incremented until the minimum transearth injection velocity was found.

Two orbits around Venus are considered in this study: a 100- by 80 000-n. mi. orbit and a 1000- by 80 000-n. mi. orbit. The 80 000 n. mi. apoapsis was chosen so as to obtain near-minimum velocity cases. For either of the two orbits, the periapsis velocity is only 600 to 700 fps below theoretical escape. In all cases, the 100- by 80 000-n. mi. orbit requires less velocity than the 1000- by 80 000-n. mi. orbit. The period of both orbits is slightly less than 3 days.

RESULTS AND DISCUSSION

As stated in reference 3, there are four periods of time between 1970 and 1975 during which free-return trajectories to Venus are possible. (Theoretically, there are free-return trajectories before the initial date of each period, but they have a periapsis below the surface of the planet and therefore are of no interest.) Orbital missions flown on free-return trajectories have the obvious advantage of requiring no velocity input at the target planet in order to return if for some reason the mission is abandoned; this study was limited to such missions.

The first group of orbital missions considered in this study has Earth departure dates between July 13 and September 11, 1970. The other three groups of missions have Earth departure dates between March 14 and May 8, 1972; October 15 and December 4, 1973; and May 8 and June 27, 1975, respectively. These periods occur approximately every 19 months.

Some of the characteristics of the above missions are presented in figures 2 through 5 as functions of Earth departure date. Part (a) of each figure presents curves of the outbound and total trip times. Considering the four time periods and a periapsis altitude at Venus of 100 n. mi., the outbound trip time varies between 76 and 146 days. The total trip time ranges from 350 to 416 days for an orbital stay time of 0.0 days and from 401 to 475 days for a stay time of 30 days. There is only a 2- to 5-day increase in both times for the missions with a 1000-n. mi. periapsis altitude at Venus. The curves of trip time follow the same trend for each period: they are nearly linear and the shortest times occur at the end of each period. The shortest trip times occur in 1972.

Figures 2(b), 3(b), 4(b), and 5(b) present the velocity requirements at Earth. The transvenus injection velocity remains nearly constant for about 20 days during each period. This velocity is the difference between the periapsis velocity of a 262-n. mi. circular orbit and the periapsis velocity of the escape hyperbola. For a periapsis altitude at Venus of 100 n. mi., the minimum transvenus injection velocity is 11 500 fps in 1970, 12 180 fps in 1972, 12 200 fps in 1973, and 11 800 fps in 1975. There are at least 26 days during each period for which the injection velocity is below 12 500 fps. There is very little change if a 1000-n. mi. periapsis altitude at Venus is considered. Also shown is the sum of the velocity required for transvenus injection and the velocity required for deboosting into orbit around Venus. The minimum sum for a periapsis altitude at Venus of 100 n. mi. is 16 600 fps in 1970, 17 100 fps in 1972, 16 400 fps in 1973, and 15 650 fps in 1975. For an orbit stay time of 30 days, the Earth entry velocity ranges from 47 500 fps in 1970 to 45 200 fps in 1975. The Earth entry velocity decreases with shorter stay times at Venus.

In figures 2(c), 3(c), 4(c), and 5(c) is shown the velocity required for deboosting into a high elliptical orbit around Venus. For the 100-by 80 000-n. mi. orbit, the minimum is 5040 fps in 1970, 4780 fps in 1972, 4045 fps in 1973, and 3860 fps in 1975. Obviously, orbit stay time does not affect this velocity increment. The 1000-n.mi. periapsis altitude causes an increase of 200 to 400 fps. Unfortunately, the departure date corresponding to the minimum velocity required for deboosting into orbit around Venus is not the same as that date corresponding to the minimum transvenus injection velocity.

The velocity required for transearth injection is shown in figures 2(c), 3(c), 4(d), and 5(d). As is true for all the time periods considered, this velocity is essentially constant for a given time period and particularly orbital stay time. The curves are very flat and there is only a 20- to 30-fps difference between the maximum and minimum in 1970 and 1972. This difference increases to about 100 fps in 1973 and 1975. The minimum velocity corresponding to an orbit stay time of 30 days and a periapsis altitude of 100 n. mi. is 4040 fps in 1970, 3910 fps in 1972, 4140 fps in 1973, and 4540 fps in 1975. Increasing the altitude at periapsis to 1000 n. mi. causes an increase of 500 to 600 fps. The minimum velocity requirements are summarized in the table.

CONCLUSION

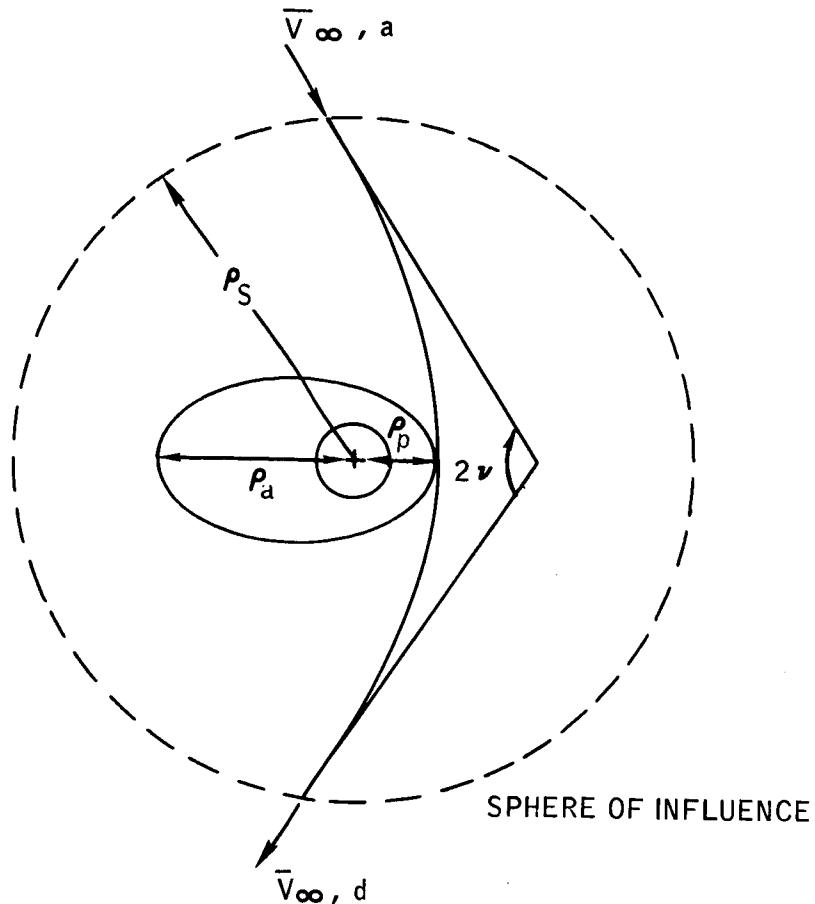
For Venus orbital missions between 1970 and 1975 using free-return outbound trajectories, the following conclusions can be made.

1. For a periapsis altitude of 100 n. mi. at Venus, there are at least 26 days during each of the four periods considered for which the transvenus injection velocity is below 12 500 fps.
2. The velocity required to get into a 100- by 80 000-n. mi. orbit around Venus varies from 3860 to 6000 fps for the time periods studied.
3. The velocity required to get out of orbit and on a return trajectory to Earth varies between 3200 and 5200 fps.
4. The Earth entry velocity ranges from 43 300 to 46 600 fps and increases with longer orbit stay times.

TABLE .- SUMMARY OF MINIMUM VELOCITY REQUIREMENTS FOR VENUS
ORBITAL MISSIONS; 100 BY 80 000-N.MI. ORBIT AT VENUS

Launch period	Transvenus injection velocity, fps	Outbound/total trip time for minimum transvenus injection velocity, days	Earth entry velocity,* fps	Venus deboost velocity, fps	Earth injection and Venus deboost, fps	Transearth injection velocity,* fps
7/13 - 9/11/70	11 500	117/446	47 500	5040	16 600	4040
3/14 - 5/8/72	12 180	116/440	46 200	4780	17 100	3910
10/15 - 12/4/73	12 200	109/435	46 300	4045	16 400	4140
5/8 - 6/27/75	11 800	117/444	45 200	3860	15 650	4540

* Values for 30-day stay time at Venus.



$\bar{V}_{\infty, a}$ Hyperbolic excess velocity of spacecraft at sphere of influence arrival, fps

$\bar{V}_{\infty, d}$ Hyperbolic excess velocity of spacecraft at sphere of influence departure, fps

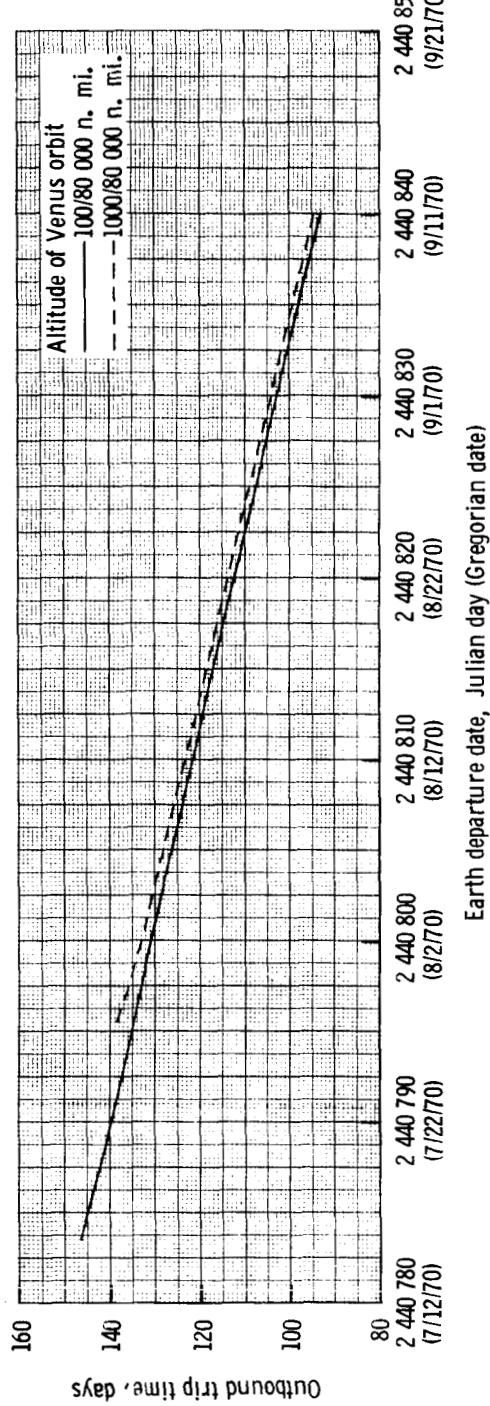
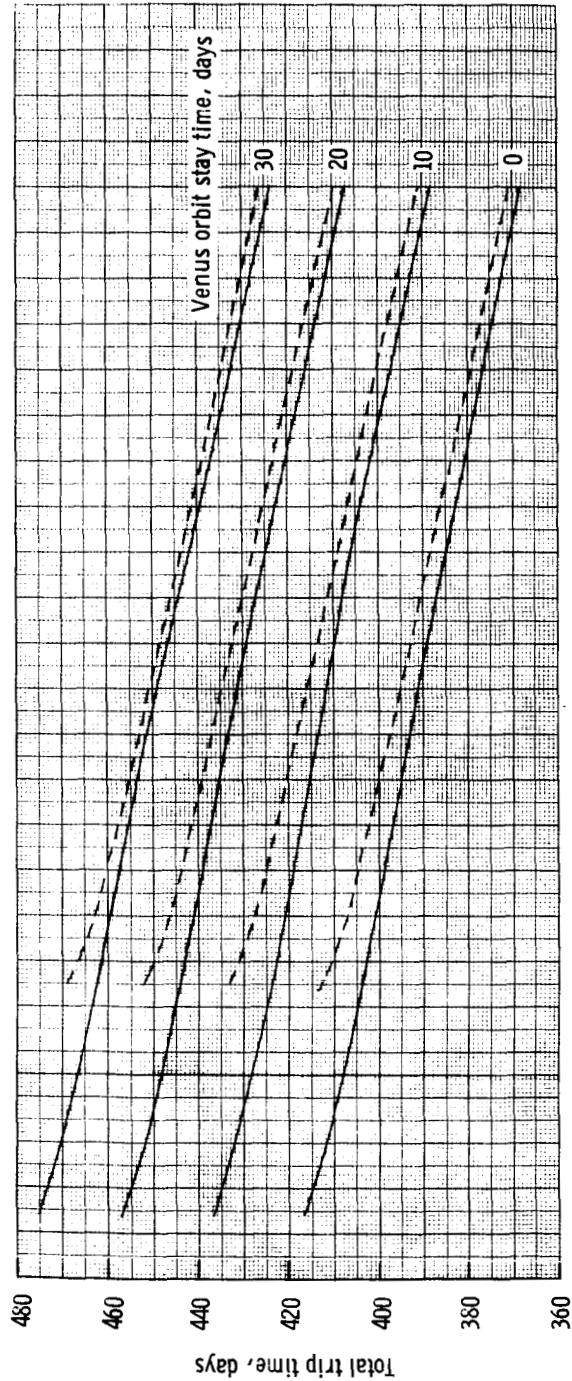
r_a Apoapsis radius, n.mi.

r_p Periapsis radius, n.mi.

r_s Radius of sphere of influence, n.mi.

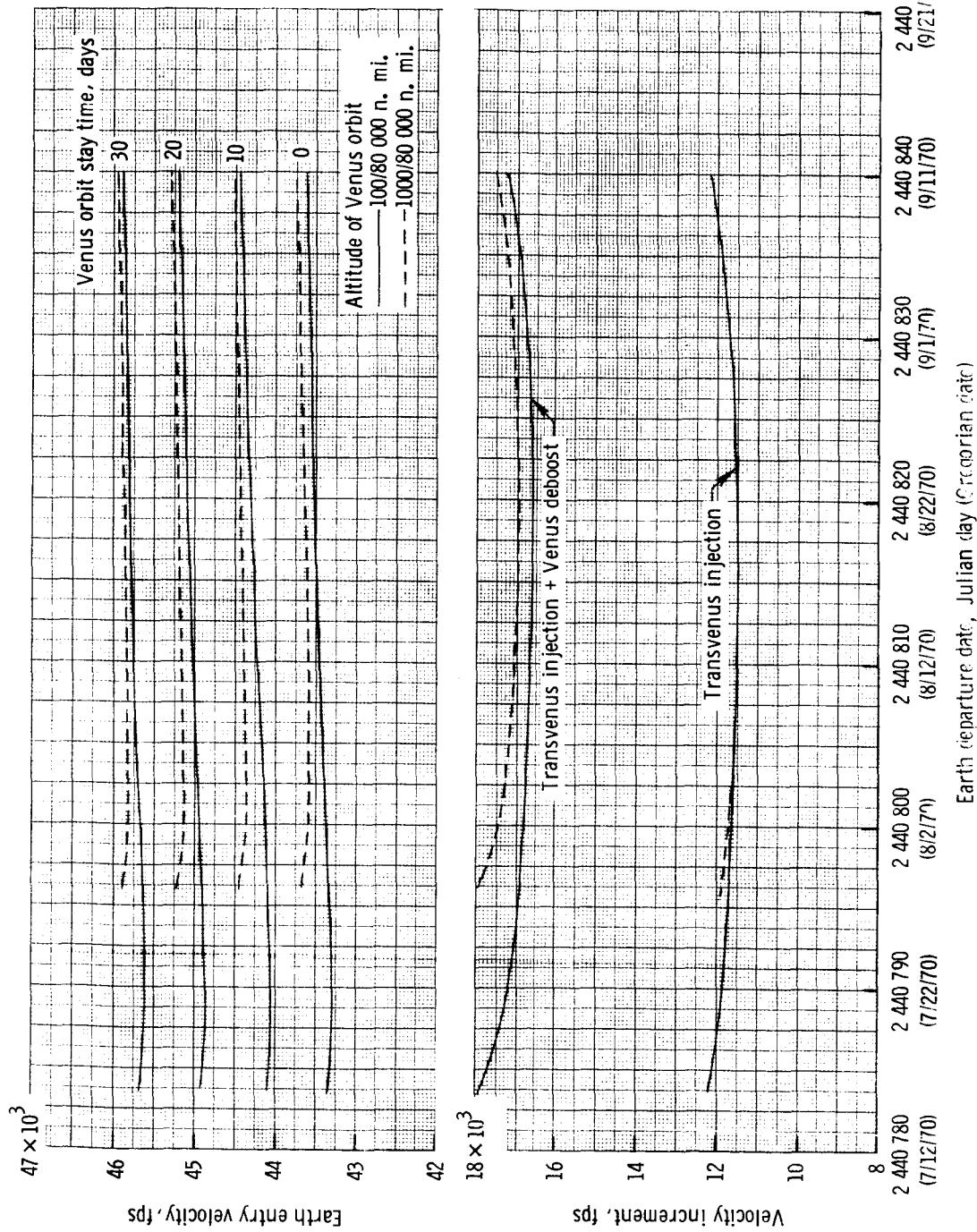
ν Half-angle of hyperbolic path at Venus, deg

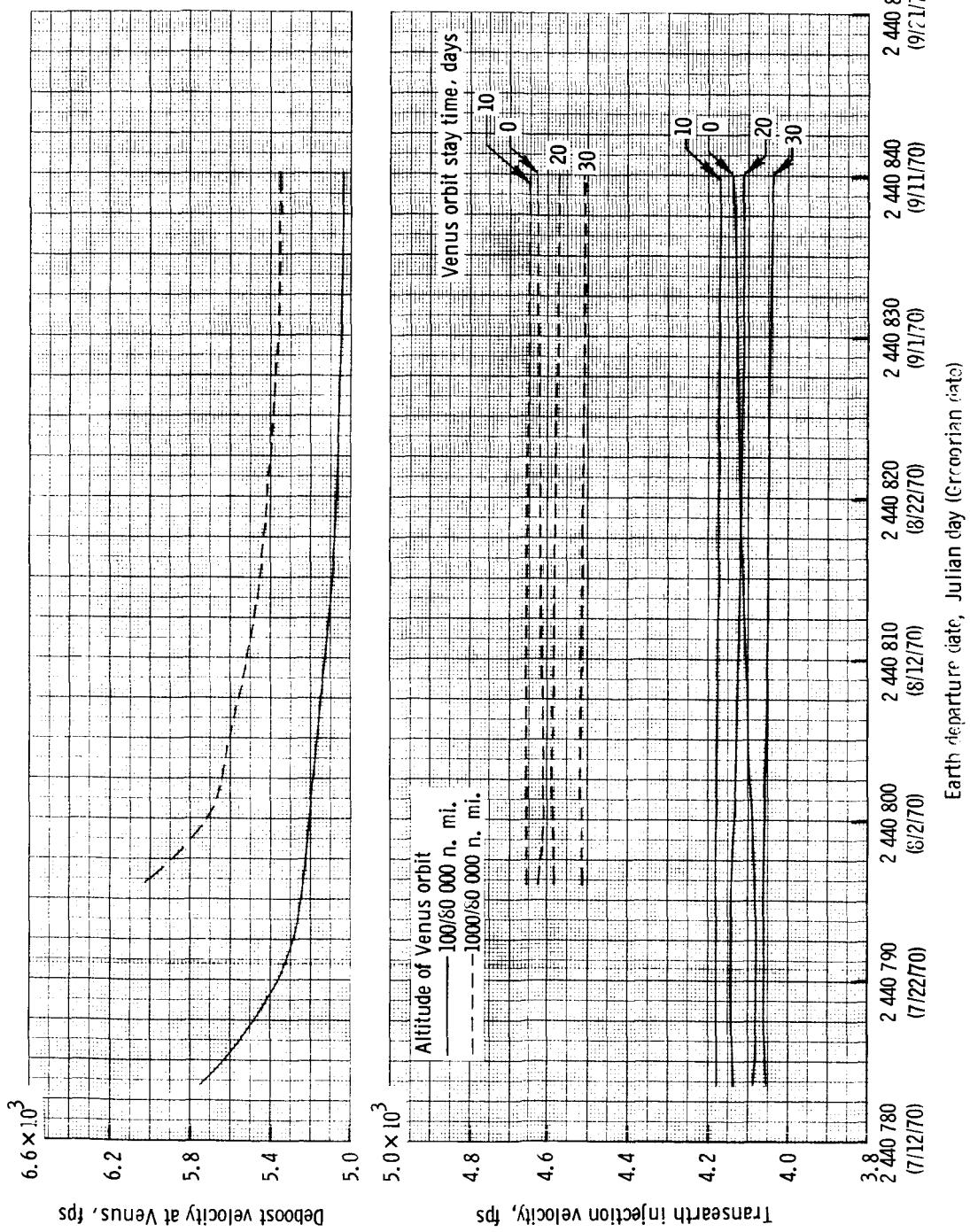
Figure 1.- Model used to describe the motion of the spacecraft within the sphere of influence of Venus.



(a) Outbound and total trip time.

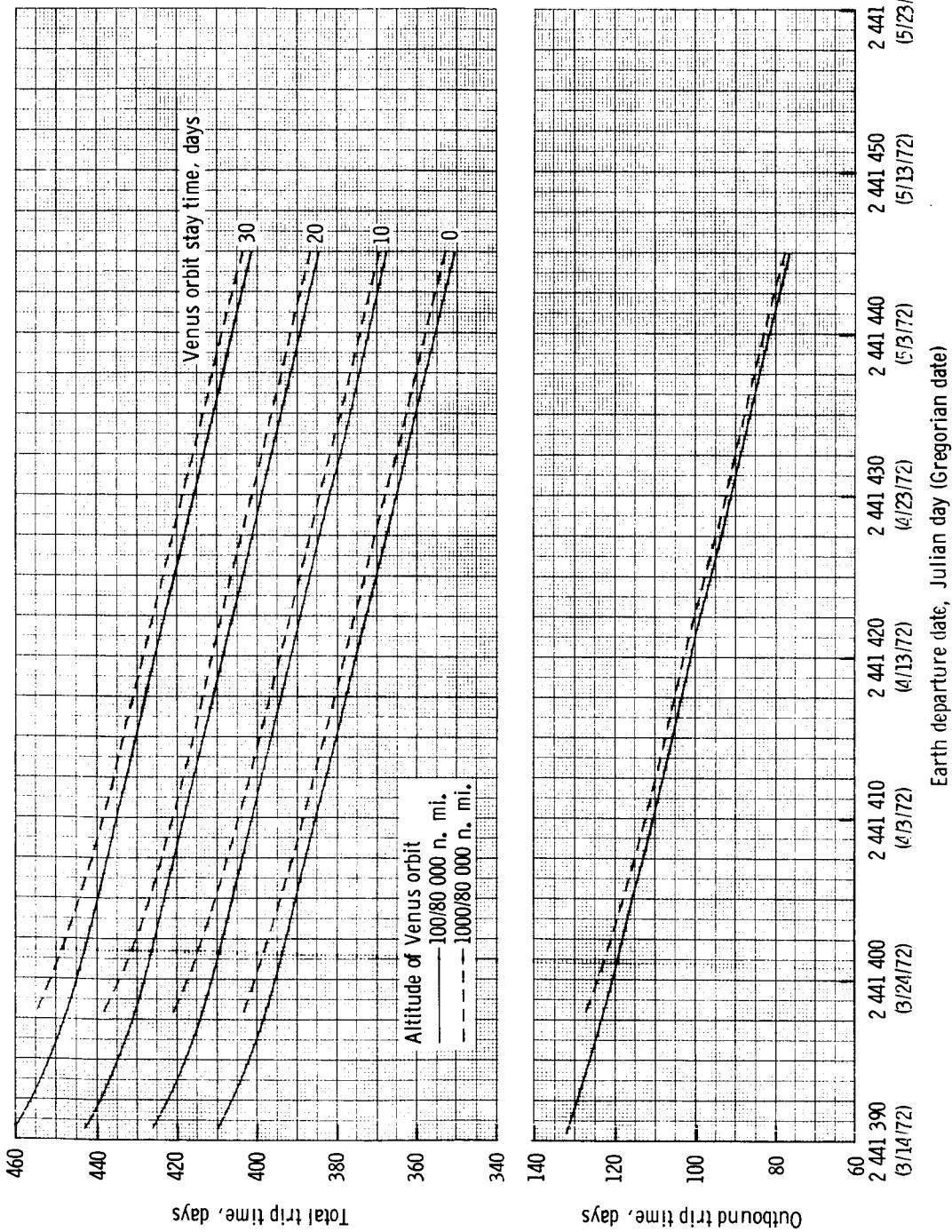
Figure 2 - Characteristics of Venus orbit missions: launch date between July 13, 1970 and September 11, 1970.





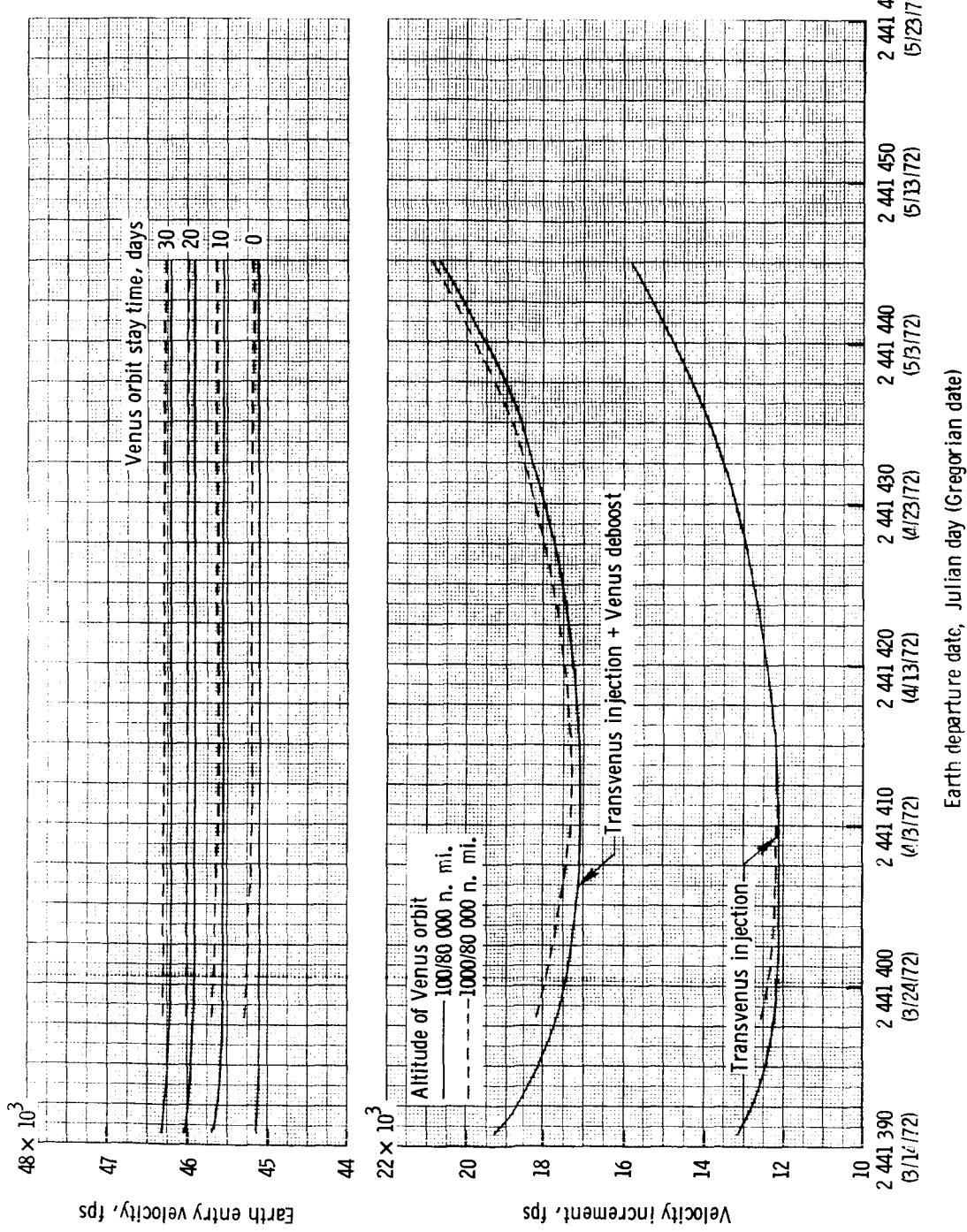
(c) Velocity increments at Venus.

Figure 2. - Concluded.



(a) Outbound and total trip time.

Figure 3.- Characteristics of Venus orbit missions; launch date between March 14, 1972 and May 6, 1972.



(b) Velocity increments at Earth.

Figure 3. - Continued.

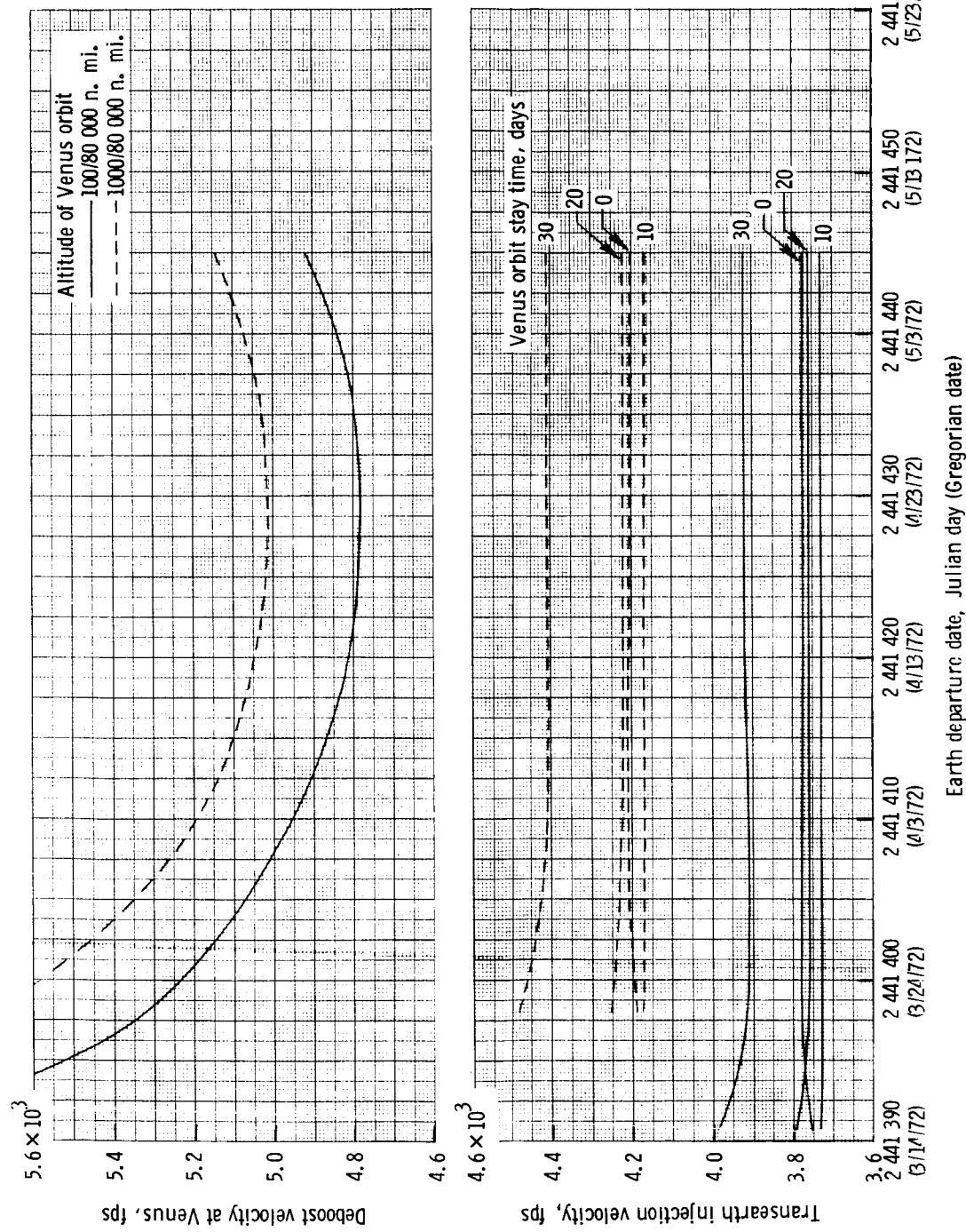
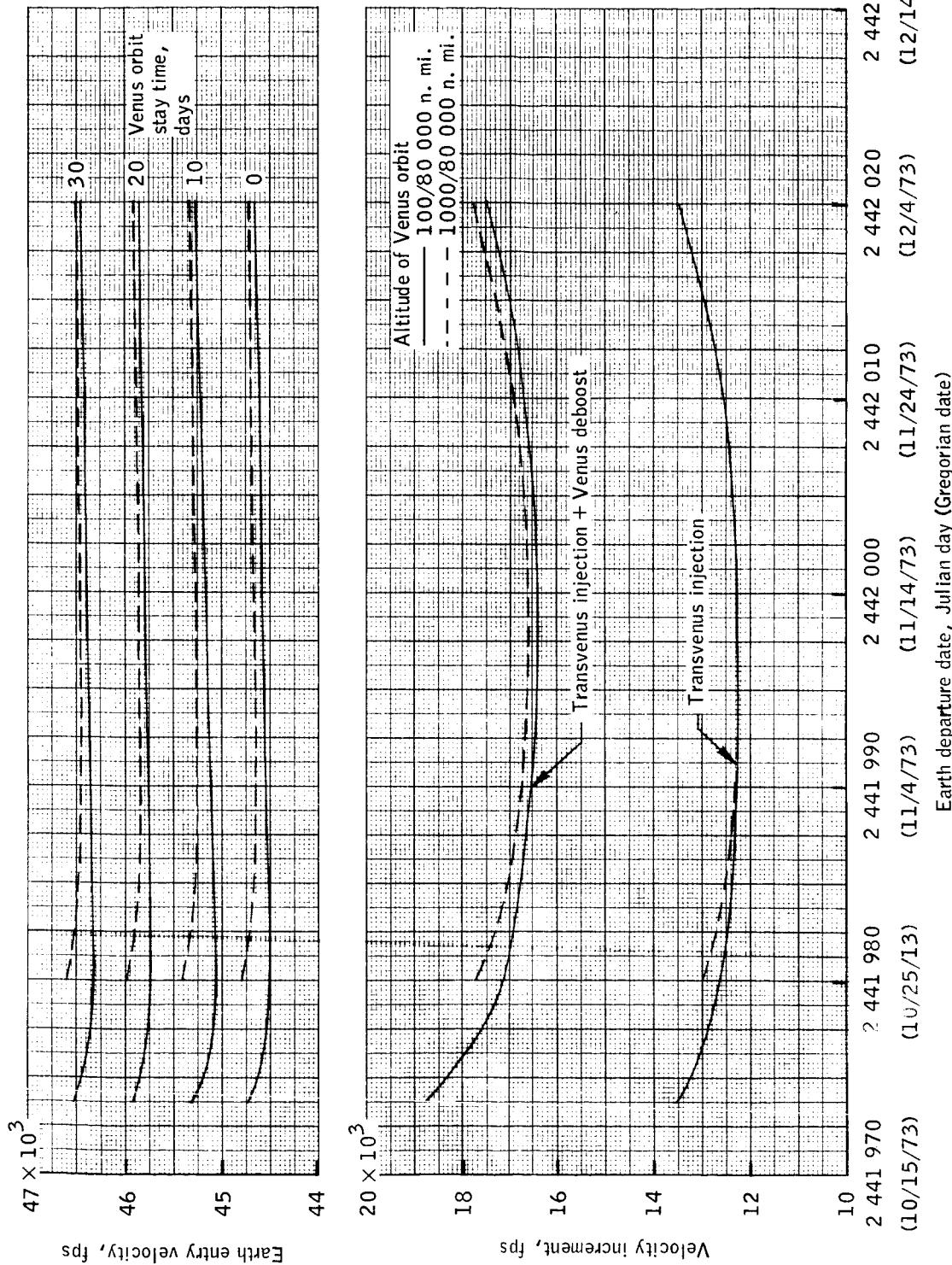


Figure 3.- Concluded.



(a) Outbound and total trip time.

Figure 4.- Characteristics of Venus orbit missions; launch date between October 15, 1973 and December 4, 1973.

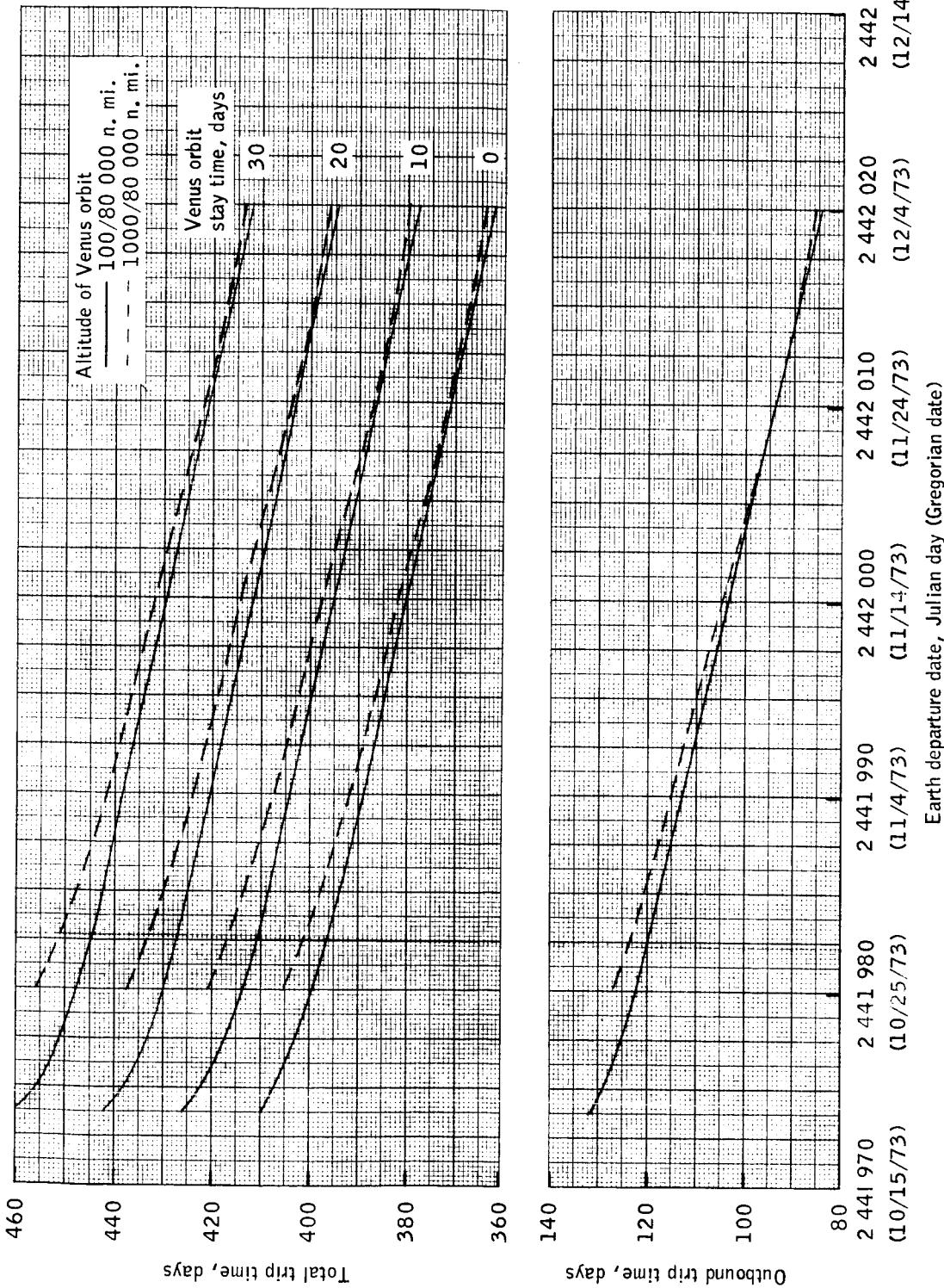


Figure 4.- Continued.

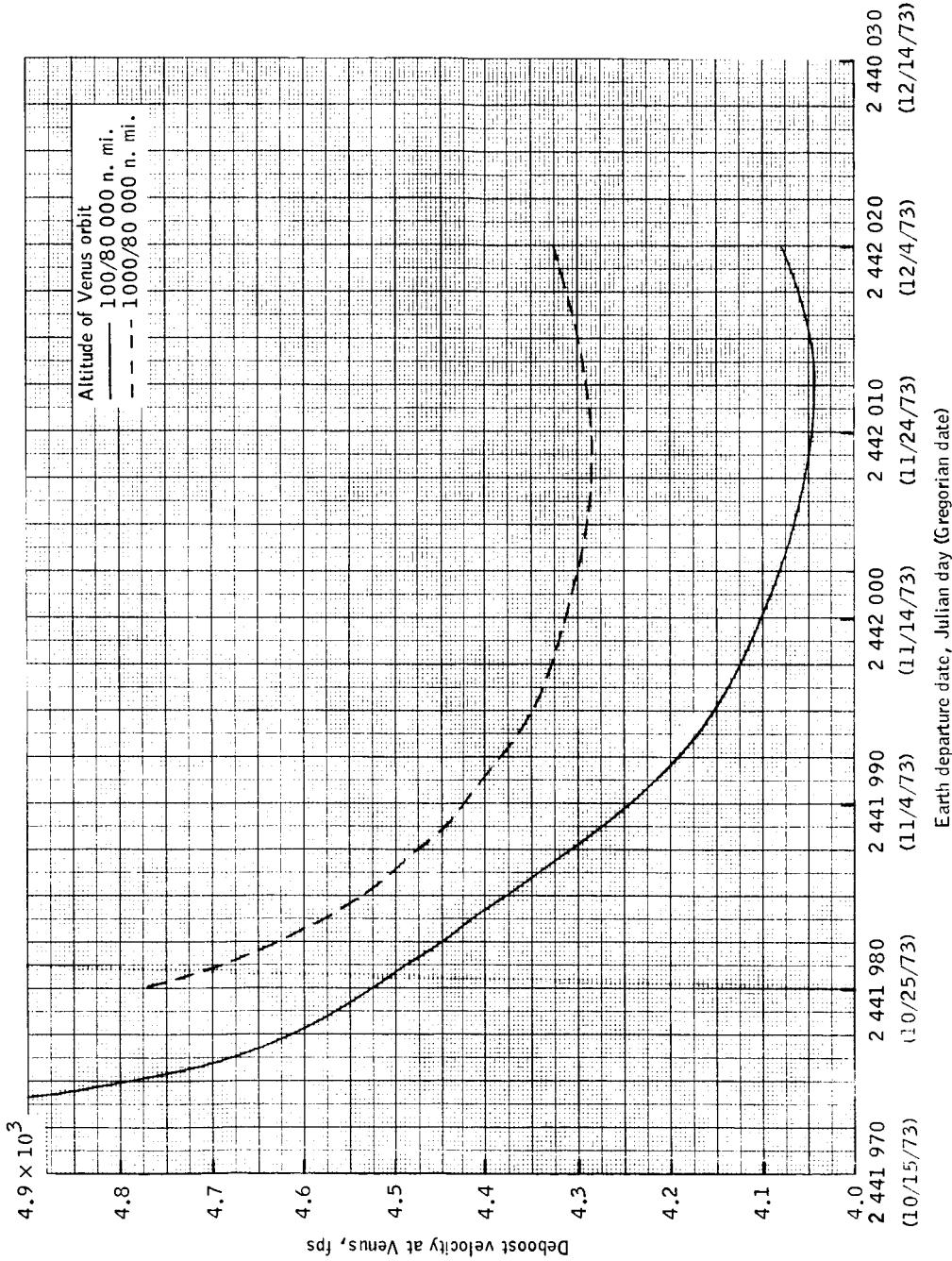


Figure 4.- Continued.

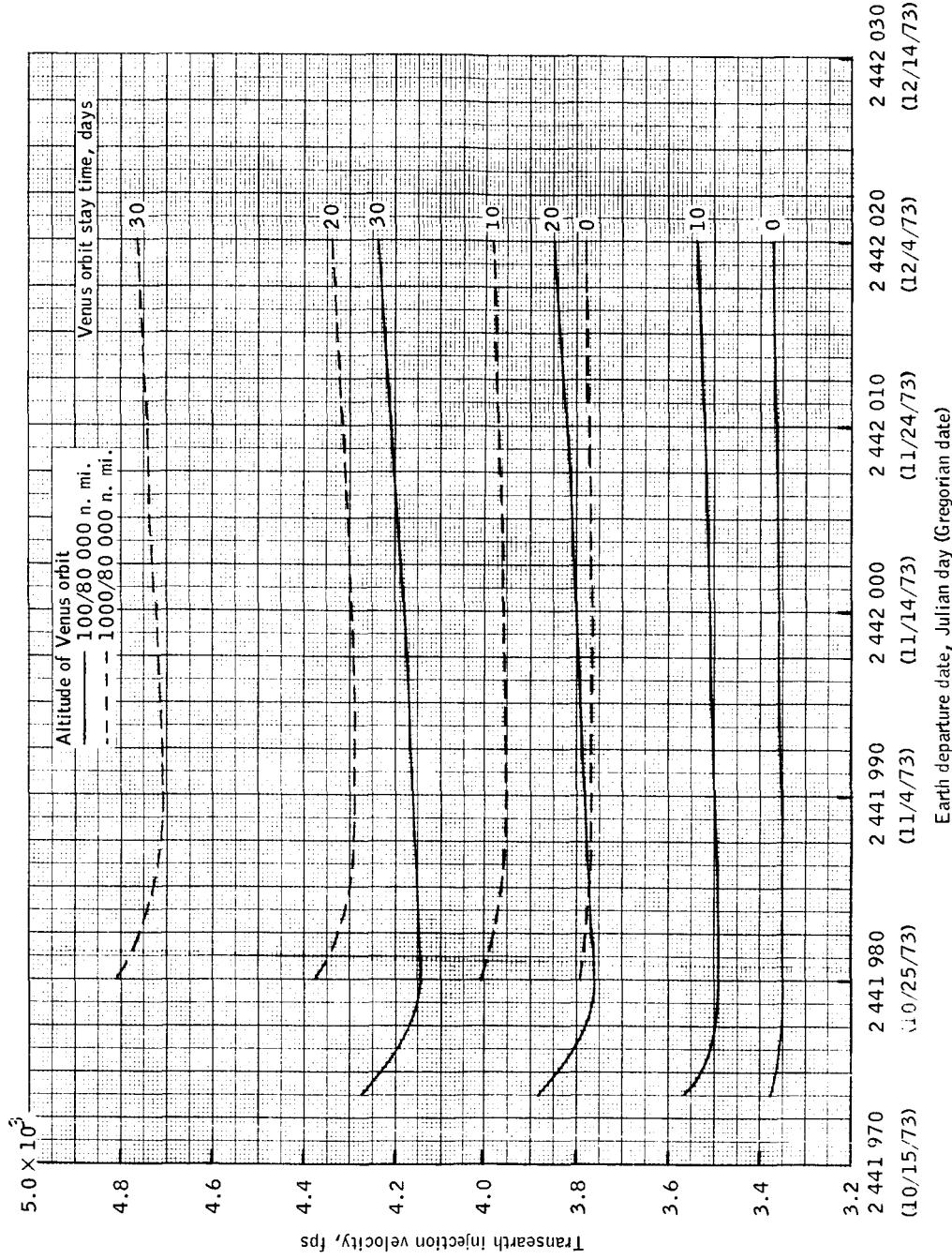


Figure 4.- Concluded.

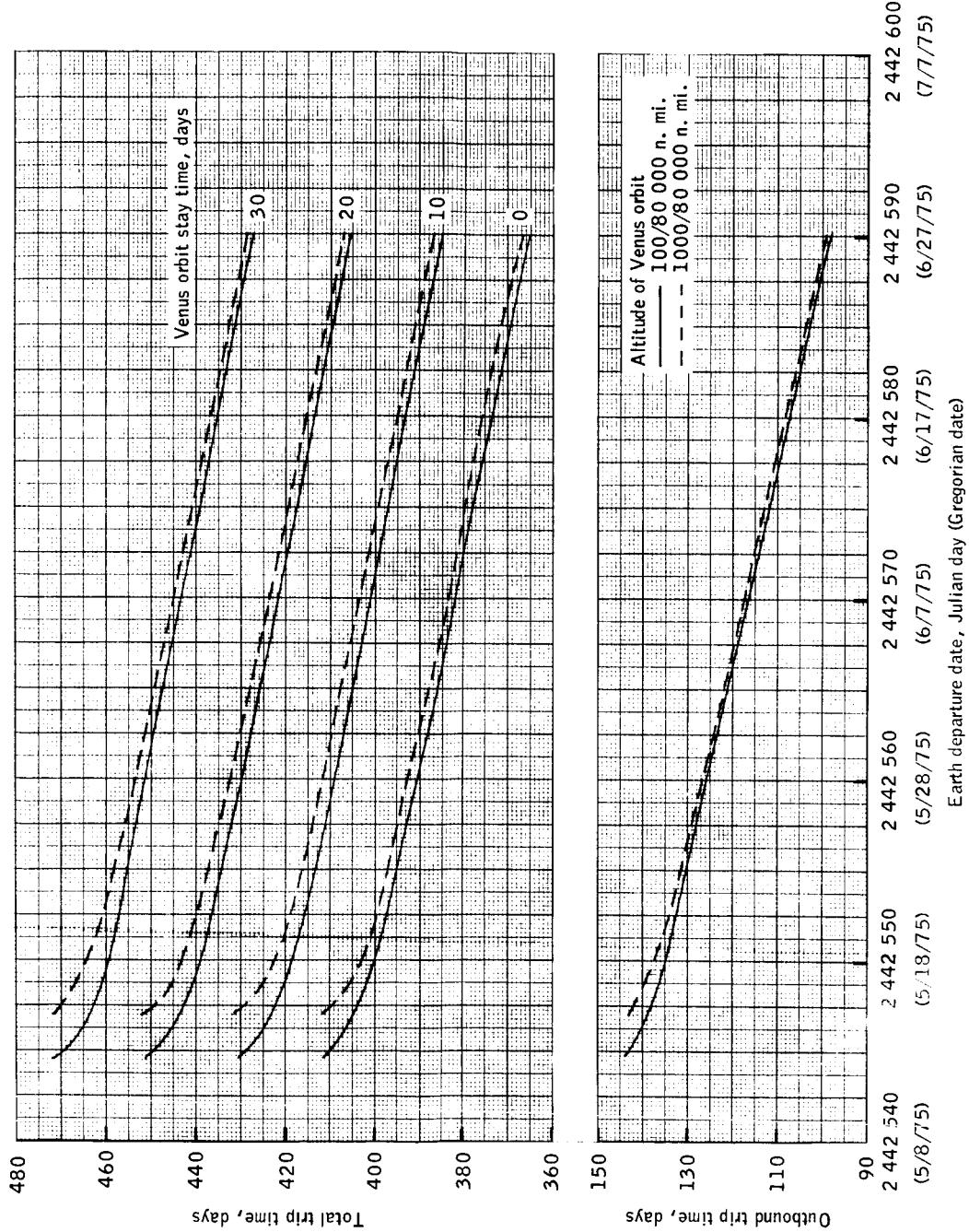
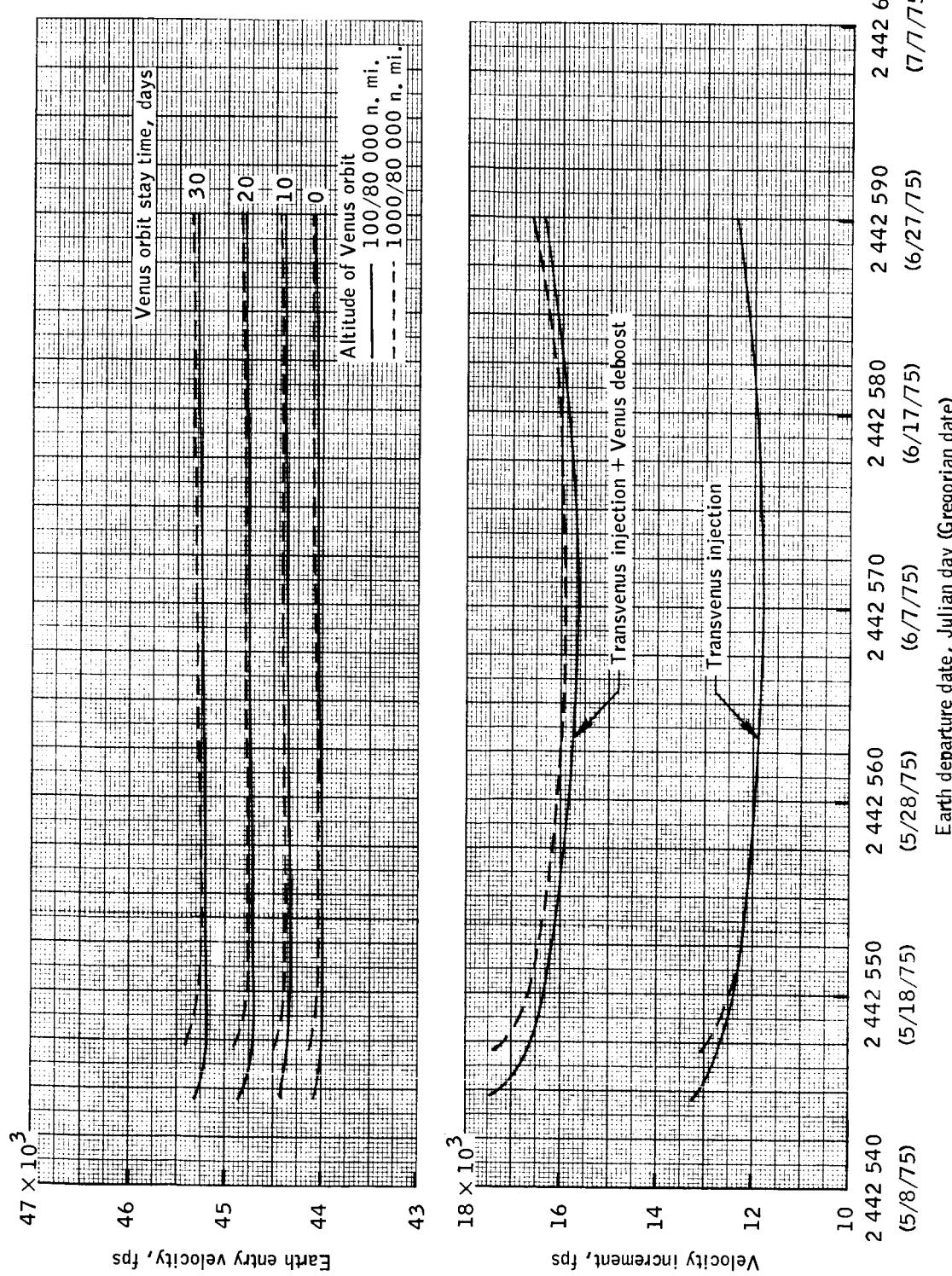


Figure 5.- Characteristics of Venus orbit missions; launch date between May 8, 1975 and June 27, 1975.



(b) Velocity increments at Earth.

Figure 5.- Continued

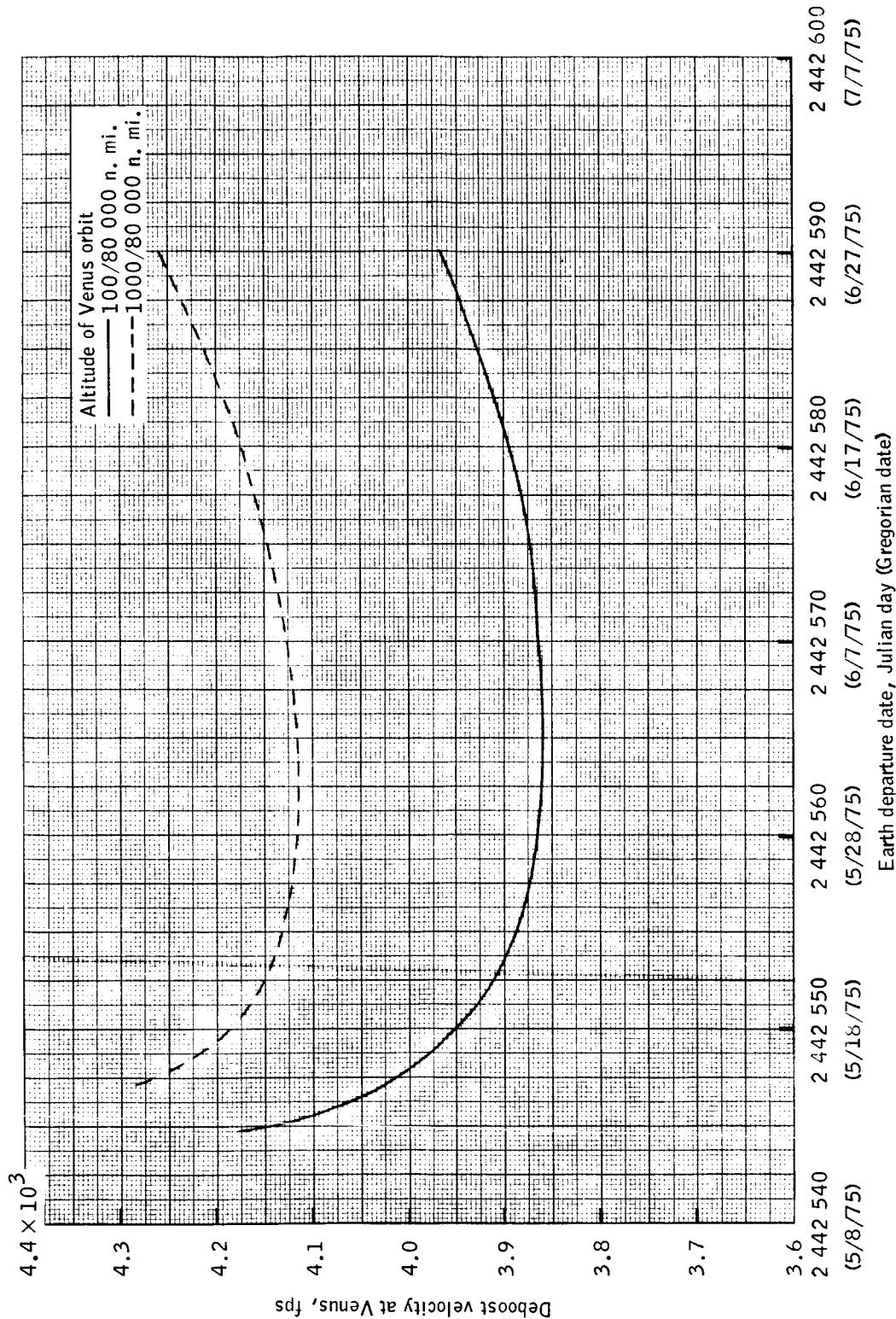


Figure 5.— Continued.

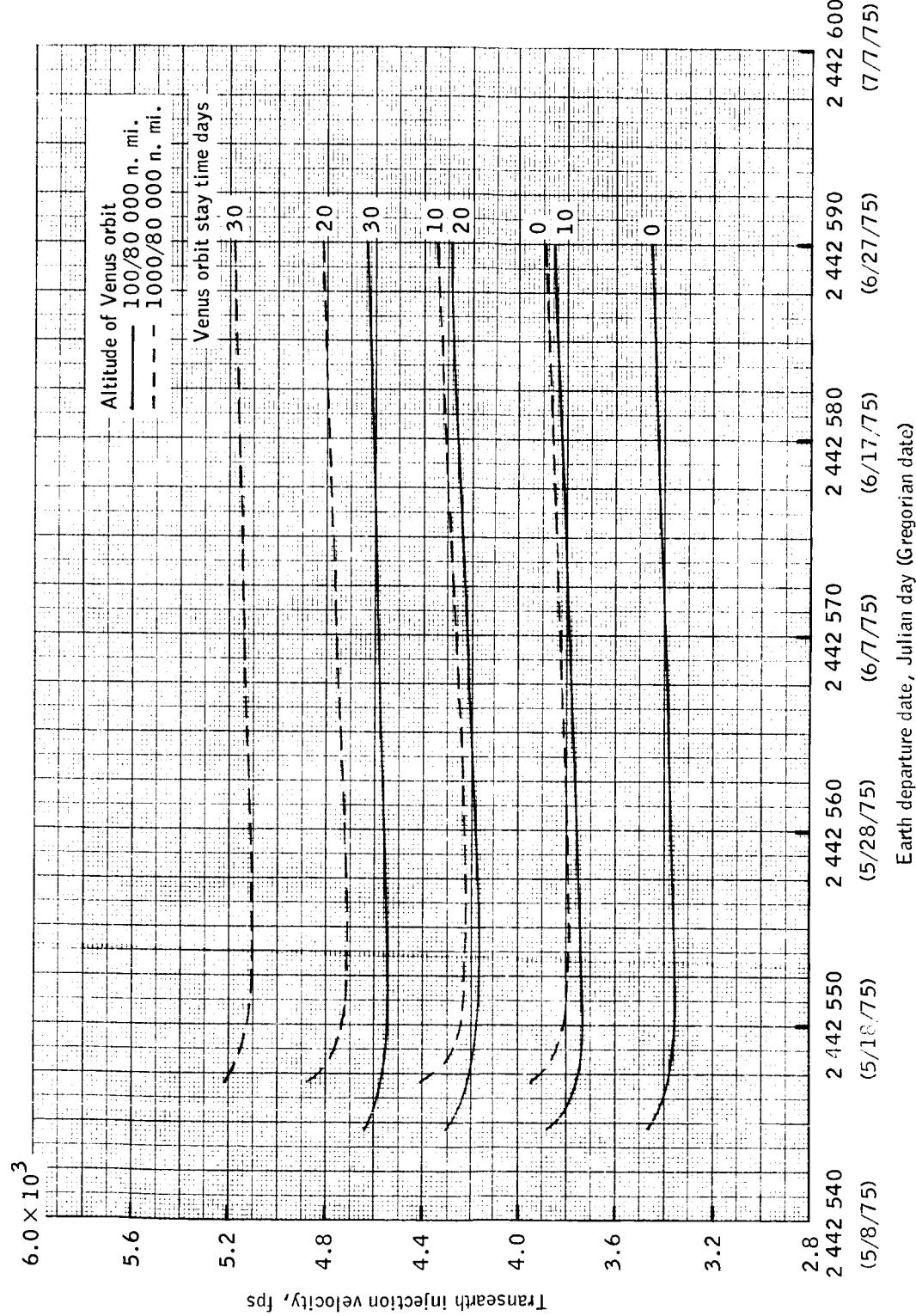


Figure 5.- Concluded.

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